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SEVERE THUNDERSTORM AND TORNADO WARNING IN REAL TIME BY COLOR D--ETC(U)

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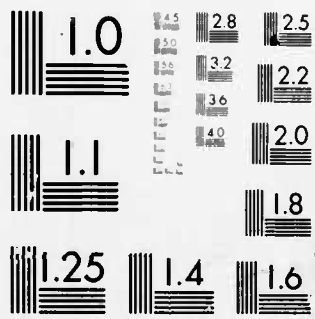
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SEVERE THUNDERSTORM AND TORNADO WARNING IN REAL TIME BY COLOR DISPLAY OF DOPPLER VELOCITIES

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1. INTRODUCTION

The meteorological research community has long been aware of the special advantages of Doppler radar for observation of the flow field within severe convective storms (e.g. Donaldson et al., 1969; Brown et al., 1971). Doppler velocities in destructive tornadic storms always indicate a mesocyclonic vortex, confirming the inference of such a circulation proposed many years ago by Brooks (1949). Although a single Doppler radar cannot provide sufficient information for the unambiguous identification of a vortex, Donaldson (1970) proposed a set of criteria for the establishment of the unlikelihood of alternative interpretations. These rules for vortex recognition were verified through dual-Doppler measurements by Brown et al. (1975) and have been refined and operationally organized by Burgess (1976).

During a five-year period of Doppler radar observations at the National Severe Storms Laboratory (NSSL), Burgess identified 37 mesocyclones. All except two were associated with damaging wind or hail, and 23 (62%) with reported tornadoes. No verified tornado occurred during the data collection period unless preceded by a mesocyclone signature, with an average lead time of 36 minutes. Brown and Lemon (1976) discussed a special subset of detectable vortex, the tornadic vortex signature (TVS), having a horizontal scale in the order of 1 km and measured shear approaching 0.1 s^{-1}. Of the 9 instances of TVS observed with NSSL radars through 1975, 7 were associated with tornadoes or funnel clouds.

2. AN OPERATIONAL TEST

Doppler radar, on the basis of current research results, has earned a recommendation as a significant tool for improvement of severe storm and tornado warnings. Both the Air Weather Service (AWS) and the National Weather Service (NWS) are planning replacement of their current operational radars, and both services are aware of the excellent reputation of Doppler radar techniques. However, Doppler capability and the processing suggested by velocity measurement does cost more money than the conventional radar techniques which deal only with reflectivity. Consequently, the two weather services, in cooperation with NSSL and AFGL, sponsored an operational test to determine the usefulness of Doppler radar, in comparison with conventional radar, in real-time warning of severe thunderstorm hazards.

The first phase of the test was conducted during the spring of 1977 from Norman, Oklahoma, using NSSL's prime 10-cm Doppler radar. Our observations were made from the second NSSL Doppler radar located near Cimarron Airport, about 40 km northwest of Norman. We brought along a pulse pair processor, tape-recording system, and color display (described by Jagodnik et al., 1975), with data input supplied by the Cimarron radar. In addition to archiving data for subsequent analysis, it was our mission during the test to provide back-up capability for the Norman radar for storms lost in its ground clutter and during times when the Norman radar was engaged in other missions.

A detailed analysis of the test results is not available at the time of this writing, while the test is still in progress. Qualitatively, however, we feel that Doppler radar technology convincingly proved its worth in meeting the challenge of the real-time warning environment. As illustration, we provide a preliminary discussion of one of the mesocyclones observed during a tornado outbreak.

3. THE NORMAN MESOCYCLONE

During the afternoon and evening hours of 20 May 1977, tornado reports were numerous in central and southwestern Oklahoma and adjacent areas of Texas. The region was bombarded with a tornado outbreak, including many instances of severe wind damage, hail, flash floods, and extremely active lightning. The earliest of the tornadoes in Oklahoma inflicted multi-million dollar havoc on Altus Air Force Base. Some 30 minutes prior to this damage the AWS-NWS Doppler forecasting team (Capt. Dave Bonewitz of AWS and Don DeVore of NWS) identified a mesocyclone approaching the Altus area and initiated a warning.

Among the more interesting events of the day was a mesocyclone which passed over Norman, with a rotating cloud base, and later a funnel cloud, in clear view of many of the NSSL people. This mesocyclone threatened Tinker Air Force Base, and in fact its earliest tornadic damage occurred just a few kilometers west of the base. The mesocyclone later split into two parts which co-existed for a few minutes before the old part died as its tornado vanished. The new part of the mesocyclone continued

vigorously and also produced a tornado. The entire phenomenon was very photogenically portrayed on our color display. Photographs are not available at this writing, but they will be shown at the conference.

The process for recognition of a mesocyclonic vortex from its Doppler velocity field initially requires a couplet of velocity extrema, a minimum and a maximum, arranged approximately equidistant from the radar but at adjacent azimuths, with the outbound (positive velocity) maximum at the more clockwise azimuth angle. A configuration of the two velocity extrema located at exactly the same range indicates pure vorticity, and varying admixtures of convergence or divergence are indicated by rotation of the axis between the velocity extrema. For example, a velocity maximum located at a greater range than its adjacent minimum indicates divergence. For vortex identification we accepted rotation of the couplet axis up to angles of 45°. We made special note of the minimum height of zero divergence, where both sides of the velocity couplet were at the same range.

In our preliminary analysis we measured distances to the nearest kilometer and read velocities from the color display to the nearest 5 m s^{-1}, which is the approximate interval between velocity contours with the Cimarron radar wavelength of 10.9 cm and pulse repetition period of 768 μs employed in these measurements. We have abstracted some features of the "Norman" mesocyclone, for both of its parts, during every elevation tilt sequence in which a vortex could be identified. We focussed our attention on the minimum height above ground of (1) the maximum velocity difference across the vortex couplet (Δv), (2) the minimum vortex diameter (D, the distance between the velocity extrema), and (3) the region of zero divergence. These are listed in the Table. In the final column of the Table we have calculated the maximum tangential shear ($\Delta v/D$) in the region of zero divergence. For a symmetrical vortex, this value is about half the vorticity.

4. DISCUSSION

We found it instructive to compare the tabular values with the times of tornado occurrences. Values of Δv (max) varied over the rather narrow range of 35 to 60 m s^{-1}. However, the maximum velocity difference was located almost always within a kilometer of the ground while a tornado was in progress, having descended from altitudes of 3 to 5 km typical of the youthful stage of the mesocyclone. The minimum vortex diameter showed a good correspondence with tornado occurrence, especially in the first tornado. Shear values also escalated in consequence of the contraction of the circulation. Vortex diameters of 1 km or less appeared to be identical to the dreaded TVS of Brown and Lemon (1976); and, indeed, Donaldson, the co-author who noted in real time the appearance of the tight, intense circulation on the ground, in a heavily-populated area, has to confess that he felt more than a little anxiety.

Tornado occurrence is also very well correlated with the minimum height of the smallest diameter vortex. In fact, the smallest vortex diameter is never on the ground except during and within two minutes of tornadoes, which is consistent with the terminology of "funnel" for describing the pendant

Table: Low-Altitude Features of the "Norman" Mesocyclone

Time CST	Δv (max) m s^{-1}	Min Height km	D(min) km	Min Height km	Div = 0 Min Height km	Shear (max) $s^{-1} \times 10^{-2}$
Old part: tornado 1840 - 1907						
1756	45	3.0	5	3.0	0.9	0.5
1804	40	4.9	3	1.7	0.9	1.2
1811	45	2.6	4	2.1	2.6	1.1
1818	35	0.8	4	0.8	2.0	0.8
1826	35	0.8	6	0.8	1.6	~0.6
1832	55	1.3	3	1.3	1.3	1.8
1838	50	0.7	4	1.3	1.9	1.0
1844	55	1.3	1	0.1	0.1	4.5
1850	60	0.7	2	0.7	0.1	3.0
1855*	50	0.1	2	0.1	0.1	2.5
1858	50	0.8	1	0.8	0.8	5.0
1904*	40	0.1	1	0.1	0.1	4.0
1909	40	0.1	<1	0.1	0.1	>4.0
New part: tornado 1911 - 1926						
1855*	60	0.1	4	0.1	>2	<1.5
1858	50	2.0	2	2.9	1.5	1.5
1908*	55	1.9	2.5	1.9	1.9	2.2
1909	55	0.9	<1	0.2	0.2	>4.5
1918	50	0.2	4	0.2	1.2	1.1
1926	60	0.3	4	0.3	0.3	1.5
1934	50	0.3	4	3.9	1.6	0.7
1942	40	0.4	4	3.0	>1	0.8

*incomplete tilt sequence

tornadic cloud. The approach of zero divergence toward the ground is another excellent indicator of a tornado in progress. Before tornado touchdown the typical pattern of velocities in the mesocyclone suggested convergence nearest the ground and strong divergence aloft increasing with height.

For storm warning purposes it is interesting to note that the earliest recognizahle mesocyclone signature occurred 44 minutes prior to touchdown of the first tornado. From the first appearance of the new part of the mesocyclone until its tornado touched down there was only a 16-minute warning. It is also of interest to forecasters that the path of the first tornado took a 30° turn toward the left when the new part of the mesocyclone appeared on its right side. This storm clearly merits further study.

5. ACKNOWLEDGEMENTS

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An operational test of Doppler radar as a real-time forecasting tool took place during Spring 1977 in Oklahoma. Participating groups included National Severe Storms Laboratory, National Weather Service, Air Weather Service and Air Force Geophysics Laboratory. The AFGL color display, mated to the NSSL 10-cm Cimarron Doppler radar, provided back-up capability to the center of operations at Norman. Also, the authors provided additional interpretation of the velocity patterns depicted on the color display for the benefit of the operational meteorologists participating in the test. Experiences in real-time identification over

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of velocity patterns characteristic of hazardous weather are summarized in this paper.